National Aeronautics and Space Administration

Simulating Ice Accretion Effects on Engine Performance

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Objectives

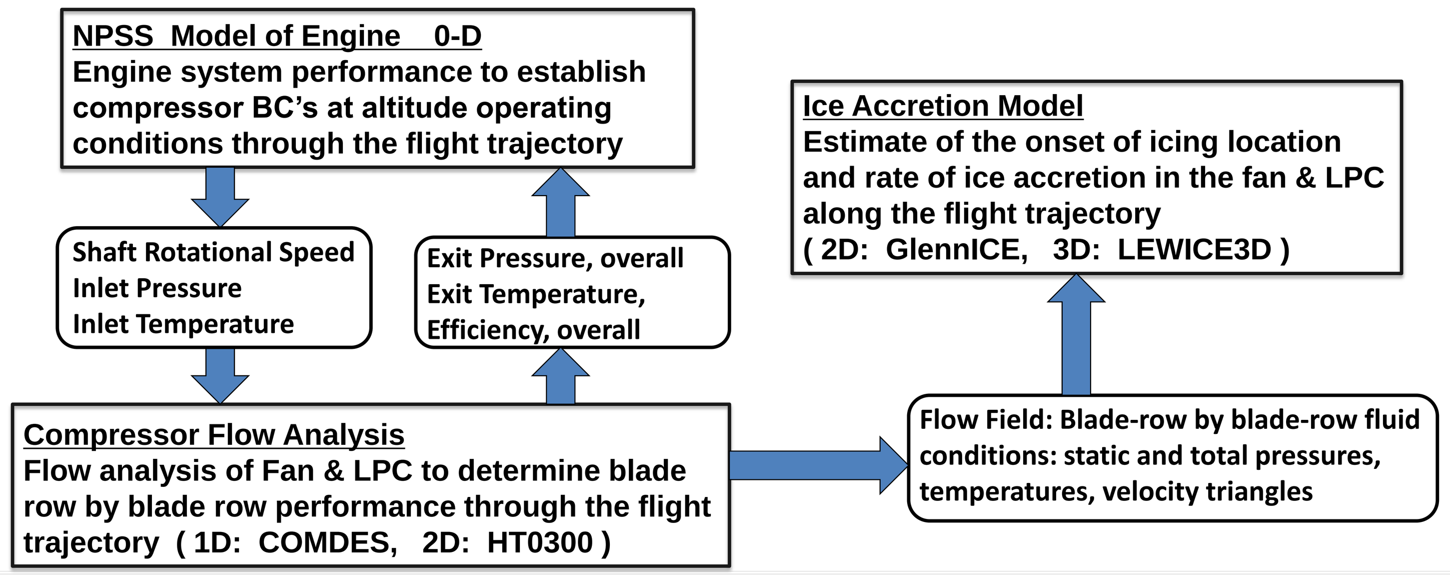
Develop a modeling tool that can be used to predict the onset of engine icing due to ice crystal ingestion. The tool will be capable of modeling the effects of ice buildup as well as its effect on engine performance. Perform a parametric study of an engine with simulated ice blockage effects at altitude conditions. Using the tool, estimate the effect of blockage in the low pressure compressor due to ice buildup (accretion), and its effects on engine performance.

Technical Challenges

Fluid properties of air with ice crystals and mixed phase water/ice is difficult to simulate in current computational fluid dynamic codes. In addition, the engine icing problem is multidisciplinary, that is, it involves not only turbomachinery aerodynamics, but convective heat transfer conduction and glaciated and mixed phase as well. The fundamental physics of ice accretion on vanes due to ice crystals is not well understood. There is currently no validated model for ice accretion from ice crystals on compression system blade surfaces, or on engine performance

Technical Approach

A notional engine is used with a typical flight trajectory that includes operating at altitudes and Mach numbers that are representative of commercial airliners. The Numerical Propulsion System Simulation code (NPSS) is used for the thermodynamic cycle analysis throughout the trajectory. The COMDES mean line compressor flow analysis code has been coupled to, and runs concurrently with the NPSS code such that the two codes exchange boundary conditions throughout the flight trajectory. Modelling the fan core and the low pressure compressors with COMDES eliminates the need for traditional maps in the cycle, and provides a higher fidelity component-level study of the compression system with and without icing. Initial estimates of the onset of ice accretion are assumed to occur in the stator within a static temperature range from 509-515 degrees Rankin. If that temperature range is reached in a stator, the level of blockage is varied in that vane and its effect on the compressor performance is estimated with the COMDES analysis code. This estimate of ice accretion potential is further refined with the GlennICE accretion code. COMDES and NPSS provide the boundary conditions for analysis with GlennICE.



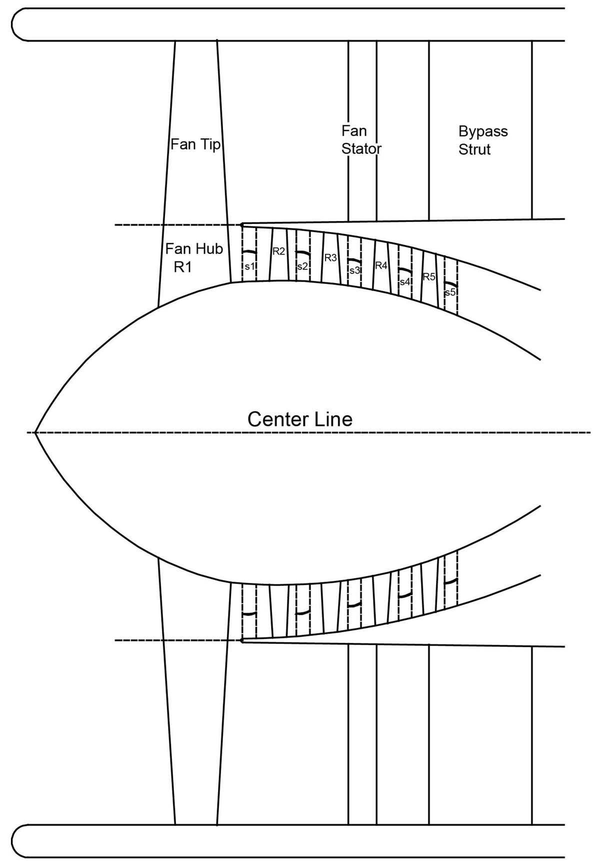
Analysis

A representative notional turbofan engine in the 40,000 lb thrust class was selected for simulating with the engine icing tools. The notional engine was modeled with the NPSS thermodynamic cycle analysis code. The flight trajectory of altitude vs. thrust and Mach number was generated by the FLOPS code. The core region of the fan and low pressure compressor, required a more detailed flow analysis to determine blade-row by blade-row flow conditions. The conceptual design flow path and blade geometry of the fan and low pressure compressor was done using COMDES. This engine was "flown" through the trajectory with the coupled NPSS – COMDES codes. The blade-row conditions were passed to GlennICE for further analysis to verify early estimates of ice accretion locations as determined by NPSS

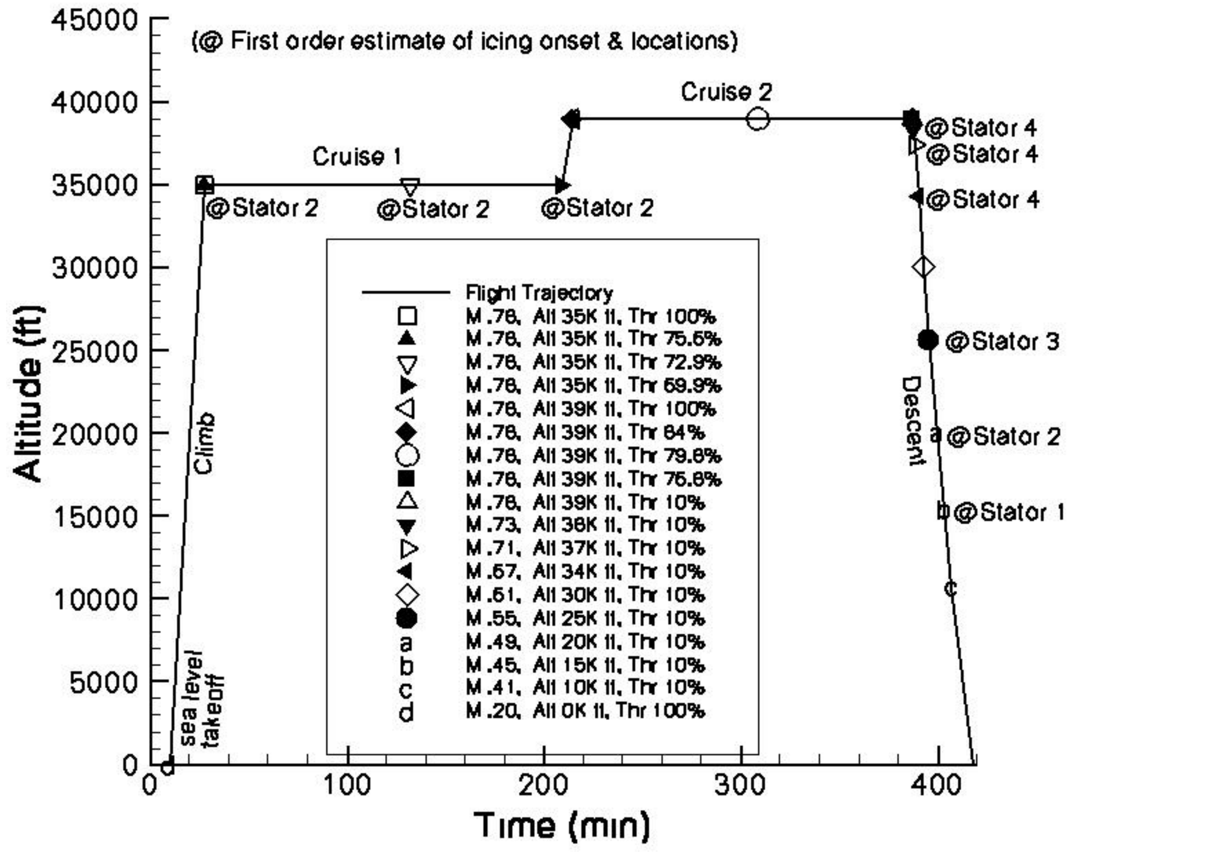
Fan & LPC Geometry Conceptual Design
(with COMDES code)

Fan :
Flow = 1122 lbm/sec
PR = 1.70
Efficiency = 89.8 %

Fan Core + 4 Stage LPC
Flow = 172 lbm/sec
PR = 2.23
Efficiency = 87. %

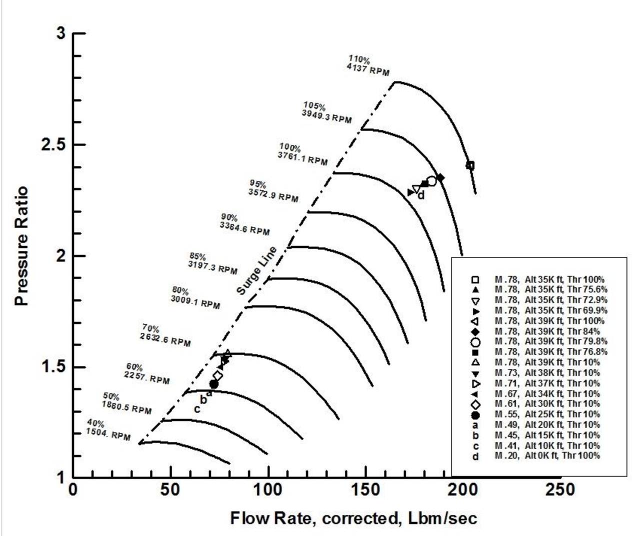


Solution - Results

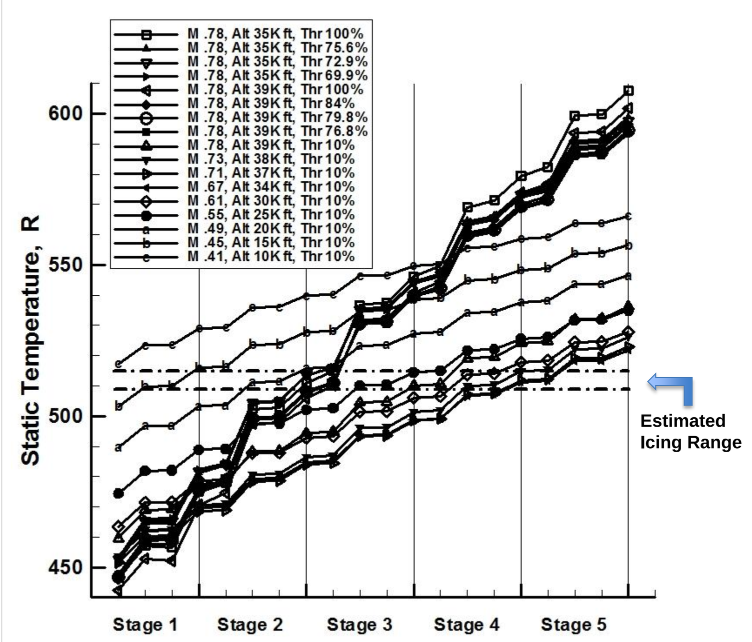


NPSS-COMDES model of engine operation through flight trajectory

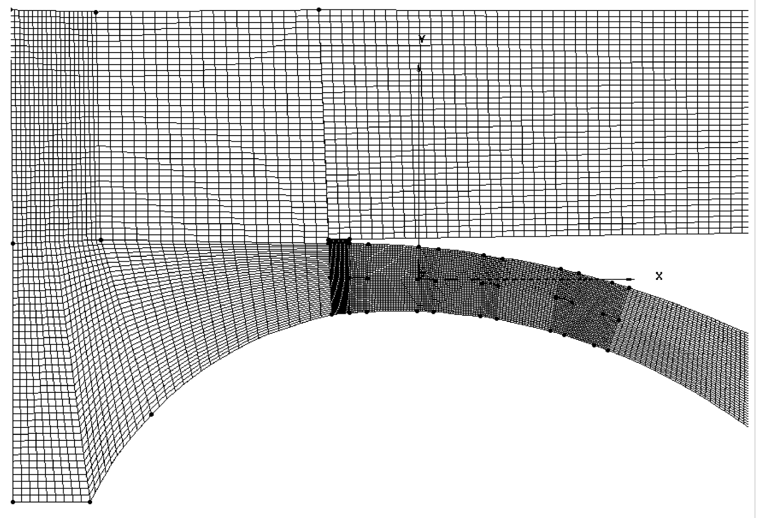
Solution - Results (continued)



Fan Core & LPC performance map generated with COMDES showing operating points along flight trajectory. Blade-row analysis provides BC's for subsequent analysis with GlennICE.



Computational grid of Fan & LP compressor for GlennICE analysis



Conclusions

This is work in progress. Further work requires fully coupling the GlennICE ice accretion code to the NPSS - COMDES codes which are already coupled. The system of three codes will exchange boundary conditions at every iteration and at each engine operating point along the flight trajectory. This capability will provide a first-order estimation of whether the occurrence of icing in the engine is likely, and at what location within the compression system. The system of codes will also assess the effects of ice buildup on the performance of the compression system, as well as on the overall engine.

The accuracy of the engine icing prediction and performance estimation tool will need to be validated by comparison to the results with known data from an engine that has experienced icing. It is planned to acquire a turbofan engine that has experienced icing, and to test it with a cloud of ice crystals ingested at the fan inlet, in the Propulsion System Laboratory (PSL) altitude facility at NASA GRC. That engine will be modeled with the tool under development and the models will be calibrated as necessary.

Additional model validation data will be obtained from the laboratory testing at the NRC in Canada, as well as the High Ice Water Content Flight Campaign.

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